Ph D. Synopsis

1. Title of Dissertation: Development of Nonwovens for Air Filtration
2. Name of Department: Textile Technology.
3. Name of Programme: Ph.D. (Textile Engineering).
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Abstract of proposed work plan:-

Air Filtration means the separation of particles from gas by passing it through a permeable medium. Quality of filtration depends upon thickness, air permeability, size of pores, bursting strength and porosity of filtering media. A non woven Textile material exhibits good filtration property because three-dimension network of fibers enclosing small pocket of void and good at properties mentioned above. The present work is aimed to develop nonwoven fabric used in air filtration. The developed fabric will be tested for properties like air permeability, size of pores, bursting strength, porosity. After that it tested for Filtration efficiency and prototype application will be developed and its performance will compared with existing product.

1. Introduction

Filters play an important role in our daily lives by providing healthier and clean products and environment. Filtration is the separation of particles from gas by passing through a permeable medium. Textile materials are generally used in the filtration of solid-gas and solid-liquid, this is because textile materials act as the three-dimension network of fibers enclosing small pocket of void volume. Due to their structures, textile fabrics have high filtration efficiencies. Textiles material do not resist the flow of the gas too much, but still its can arrest the particles easily. [1, 11, 12]

Therefore, many types of filters have come in the market now a day, there is a need to test the filters before its actual use, so that we will get-to-know that how much filtration efficiency it can give for a particular filter application. According to the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), the standards are given for testing the filters to be applied in a Heating, Ventilator, and Air Conditioning (HVAC).

2. Review of Literature and Development in the subject

2.1 Introduction:-

Filtration is the separation of one material from another. The main purpose of filtration is to improve the purity of the filtered material, by maximizing the possibility of collision and the subsequent retention of the suspended particles with fibrous structure while minimizing the energy loss. Textile materials are used in filtration of air, liquid, manufacturing foods, industries production, air condition system, engines, vacuum cleaner etc. woven and nonwoven fabrics are particularly suitable for filtration because of their complicated structures and considerable thickness. The efficiency of filtration in industrial fabrics is affected by their porosity, air permeability and pore size. Polyester is the widely used fiber in gas filtration because of its strength, relatively high temperature resistance (up to 150 degree Celsius) and low cost. [1, 11]

2.2 Suitability of fibre for nonwoven air filter fabric

D kalaivani, et al. [2] studied on thermal bonded polyester staple fiber nonwoven fabrics. The nonwoven fabrics have been produced, with variables like different proportions of binder fibers, direction of web laid and bonding time and with bonding temperature as constant. The influence of process variables on fabric properties, such as bursting strength, air permeability, bubble point diameter, mean flow pore diameter and filtration efficiency with three different particle were studied. During his study maximum efficiency achieved was 93.13 % which is around 13% higher than that spunlaid fabric. For 80g/m2 fabric with o.3 u particles, the filtration efficiency of spunlaid fabric was only 38% which around one and a half time lesser than 80g/m2 of thermal bonded fabric; 90g/m2 fabric show equal and better properties than 100 g/m2 fabric.

2.3 Production technique of nonwoven fabric for filter

A das, et al., [3] have studied filtration characteristics nonwoven fabric. Namely thermo bonded and needle punched, with wide range of physical parameter has been studied. A computerized air filtration fabric apparatus has been designed and developed for measuring air filtration characteristics of different types of filter fabrics. In this study needle punched fabrics perform better as a filter fabric in comparison to thermo bonded nonwoven.

Rajesh D. et al. [4] developed a needle punched fabric from flax fiber for the air filtration application. Only flax fiber waste was utilized as a raw material. They produced different nonwoven fabrics from flax fiber waste by varying the machine variables which influences physical parameters of fabric. They measured the air permeability, mechanical properties, filtration efficiency, and pore size distribution of developed fabrics. The tensile strength of needle punched nonwoven in the cross machine direction is higher than the machine direction. After investigation they found that, calendaring effect of nonwoven flax fabric increase filtration efficiency by regulating density and permeability.

Nishant Mohurle et al. [5] studied on analysis on fabric filtration material which is dust collector when coal is burnt in a power station approximately 30% of the weight of the coal evolves as a fly ash particulate emission which must be prevented from passing to atmosphere. The Paper Discuss the use of different filtration material (Fibre) for Pulse jet Fabric Filter in Filtration Media for filter bags. In present work a effort has been made to found service life of filter bag developed for efficiently collecting particles over the size range of 0.1 – 1,000 mm. This particle collection effiency is influenced by the multiple opportunities for a particle to be captured as it attempts to pass through a dust cake & fabric.

Sakthil S, et al. [6] studied on development of needle punched nonwoven fabrics from reclaimed fibers for air filtration application. This paper reports an investigative study on the fabrication and measurement of the air permeability, mechanical properties, pore size distribution, and filtration efficiency of different nonwoven fabrics produced from reclaimed fibers by analytically changing the machine variables to manipulate the physical parameters of the nonwoven fabrics. Reclaimed fiber of cotton (60%) and polyester (40%) blend was used. As fibers became more tightly packed in nonwoven fabric, it becomes more difficult for particles to pass through the body of the fabric. This happens with increase in fabric density, the consolidation of the web increased with the resultant increase in dust weight and dust holding capacity. The results in this study show overall improvement of all filtration characteristics due to the calendaring. This was an investigative study proposed for utilizing reclaimed waste fibers for developing inexpensive disposable filtration media for air and dust filtration, mainly for household and industrial air-conditioning. The production of reclaimed samples by combining different nonwoven fabrics through the needle punching process was also explored. The strength and permeability results obtained for these fabrics were promising and consistent for the intended end-uses.

Hongxiao Xiao, et al. [7] studied on the production process, products structure, performance and wide application range of nonwoven filter material which were made of glass fibre. They analysed the importance glass fiber in the filter fields and proposed application in future. In this study the filter material of glass fiber composite, coated glass fiber filter were compared with other existing filter materials .Glass fiber filter material has many special advantages which satisfies the increasingly stringent environmental requirements. They have wide range of applications in the field of air purification, so the glass fiber filter material is an important study subject.

Kazumaro Fujiwara et al., [8] have a patent on a nonwoven fabric air filter for internal combustion engine produced by forming multiple layers air-laid nonwoven fabric composed, mainly of polyester binder fibers of 1 to 10 mm fiber length .

A thin uniform nonwoven fabric air filter for internal combustion engine with pleats configuration, having an upper layer side (fluid inflow side) composed of thick fibers, having a lower layer side (fluid outflow side) composed of thin fibers, and having a last fluid outflow side layer composed 100% of polyester binder fibers, with thin uniform nonwoven fabric air filter is comprised of air-laid nonwoven fabrics whose weight per square meter, apparent density and dry-heat shrinkage factor after 300 hr at 100˚C are 100 to 350 g/m2, 0.04 to 0.3 g/cm3 and 3% or less, respectively. This thin uniform nonwoven fabric air filter is free from environmental pollution, realizes high dust collection efficiency and ensures prolonged life.

Wolfram Schultheiss, et al. [9] have a patent on multi-layer air filter including a filter layer which is covered on the raw gas side by a pre-filter layer, which pre-filter layer includes a dry laid electro statically active nonwoven, preferably a staple fibre nonwoven with a surface weight of 10-100g/m2. The filter can be advantageously used as vacuum filter bag. The filter has an extended service life due to an improved separation efficiency combined with a reduced tendency of clogging.

2.4 Multilayer nonwoven fabric for filter application

Stanislaw dolny, et al. [10] studied on modern nonwoven filter fabrics covered with a microfiber layer ,make it possible to carry out surface filtration. A dust cake forms only on their upstream side and influences the air flow resistance across the filter. The mode of formation of the flow resistance caused by such a fabric during the separation of very fine wood dust particles was the subject of a comparative investigation using a homogeneous,

standard nonwoven filtering fabric. The experiments carried out in a pilot-scale pulse-jet bag filter enabled a detailed description of the increase in pressure drop across the dust cake formed during filtering cycles repeated hundreds of times. Based on the results obtained the difference in this filtration parameter between polyester-based nonwoven filter fabrics with a standard and a layered structure with microfiber was also shown. The addition of these results to the existing characteristics of separating properties of the polyester nonwoven fabrics type KYS of both the PROGRES and FINESS series provides a comprehensive assessment of their usefulness as filter media in pulse-jet bag filters used in the wood working industry at a very broad range of basic flow parameters. The more difficult the flow conditions during the filtering process, the more advantageous the use of the nonwoven fabrics covered with a microfiber layer for wood dust, due to a low increase in energy consumption and the expected significant improvement in the quality of the cleaned air.

2.5 Analysis of Fabric

D Bhattacharjee, et al. [11] investigation on air and water permeability characteristics of spun laid heat bonded type fabrics show a very close liner correlation between both permeability values. The ratio of water permeability to air permeability is function of the pressure heat at which these values are measured. The author concluded excellent linear correlation between air and water permeability. The relationship indicates that for the limiting case for which the air permeability is zero, the water permeability also becomes zero.

V. K. Kothari, et al. [12] studied on filtration behaviour of woven and nonwoven fabrics at different air flow rate, dust feed rate, dust loading, time interval and dust particles. It was observed that the pressure drop increase with the increase in airflow rate for both woven and nonwoven filter. In general, the pressure drop in case of woven filter is found to be higher than that in case of nonwoven filter. The filtration and cleaning efficiencies of nonwoven fabric for a certain type of dust particle, are found to be affected by the dust feed rate and air flow rate.

Table No.1: European Normalisation standards recognise the following filter classes

Uses	Class	Performance	Test	Particle size*	Test Standard
Primary filter	G1	65%	Avg. Value	>5 um	BSEN779
	G2	65-80%	Avg. Value	>5 um	BSEN779
	G3	80-90%	Avg. Value	>5 um	BSEN779
	G4	90%	Avg. Value	>5 um	BSEN779
Secondary filter	M5	40-60%	Avg. Value	>5 um	BSEN779
	M6	60-80%	Avg. Value	>5 um	BSEN779
	M7	80-90%	Avg. Value	>2 um	BSEN779
	F8	90-95%	Avg. Value	>2 um	BSEN779
	F9	95%	Avg. Value	>1 um	BSEN779
Semi-HEPA	E10	85%	Min. Value	>1 um	BSEN1822
	E11	95%	Min. Value	>0.5 um	BSEN1822
	E12	99.5%	Min. Value	>0.5 um	BSEN1822
HEPA	H13	99.95%	Min. Value	>0.3um	BSEN1822
	H14	99.995%	Min. Value	>0.3um	BSEN1822
ULPA	U15	99.9995%	Min. Value	>0.3um	BSEN1822
	U16	99.99995%	Min. Value	>0.3um	BSEN1822
	U17	99.999995%	Min. Value	>0.3um	BSEN1822

2.6 Application of nonwoven as air filter

Tadeuszdziubak. et al. [13] in this paper experimental research on nonwoven filter fabric for intake air filtration in the IC engine of an Off Road vehicle was studied. In this paper, filtering media used as porous membranes in air cleaners of modern motor vehicles have been analysed. A relation that defines the air filter life has been presented and a dust absorption coefficient of a filtering medium has been defined. Results of examining the filtration efficiency, threshold, and restriction characteristics of the filtering media under consideration have been analysed. The dust absorption coefficient of a nonwoven filter fabric has been determined for the fabric working at different air velocities during the filtration. The impact of the particle size distribution of dust changed by the intake air pre-treatment in a inflow cyclone, on the characteristics of the nonwoven fabric under test and on the value of

its km coefficient has been examined. The benefits gained from two-stage air filtration have been indicated.

Tharewal P. G., et al..[14] studied on application of nonwoven for air filtration used in automotive, home, food products, chemical industry, coal fire power stations, face mask. Both woven and nonwoven fabric can be used for filtration purpose but nonwoven fabrics are preferred to woven fabrics for improved performance in case of air filtration. The nonwoven fabrics are potentially better filters. Moreover, they are cheaper to produce. So, the use of nonwoven filter fabric has been growing steadily.

2.7 Existing Methods For Testing Filtration Efficiency:-

An efficient air filter is a better choice to capture different air particles. The efficiency of an air filter depends on the types of air particles and can be tuned by the particles capturing mechanism. Fiber based nonwoven HVAC having an efficiency regulated by ASHRAE, HEPA filters capture tiny particles of 0.3 micron with =>99.97% filtration efficiency. However HEPA have high pressure drop than HVAC and quickly clogging due to limited specific surface area.

Particles filtration is mostly characterized in terms of filtration efficiency, pressure drop, temperature changes and quality factor. Air filtration can also be characterized in terms of filter resistance, minimum efficiency reporting value (MERV) and most penetrating particle size (MPPS). Filter resistance determines the breathability of the filter and is more related to pressure drop. MERV is minimum fractional particle size efficiency in three different particle size ranges. MPPS is the particle size at which no set of capture mechanism is able to filter it. The typical MPPS for most filters is in between 0.1 and 0.3 micrometer. Recently, the term specific filtration efficiency is coined, where filtration efficiency is normalized to basic weight of the filter media. [16, 17]

2.8 Properties Affecting Filtration Efficiency of Filter Media:

Among various arduous situations, filtration at high temperature is one of the most challenging tasks. This has led to many promising developments in particles collection technology. If the gas stream can be clean at elevated temperature, then processes can be made more efficient in term of energy and more integrated in term of process technology. Practical experience of using high temperature filtration shows that apart from utilizing the heat of production gases, the potential advantages of it may be also express in the possibilities

of an increase in equipment service life due to its high dew point operation and saving in capital and operating expenditure. However, high filtration temperature while beneficial for cycle efficiency, impose severe limitations on the mechanical durability and corrosion resistance of components in the cleaning gas unit among other aspects. The disadvantage is that the elevated temperature means increase viscosity of gas and consequently much higher resistances. Increased temperature also means decreased gas density with a consequent reduction in blower performance. Flexible filtered medium makes them less susceptible to thermal shock, but gives more propensities to a loss of material strength through rough handling, excessive temperature and corrosion. Fibers can survive exposed to temperature above their continuous operating temperatures, but the high heat results in loss of tensile strength of fabric and less effective cleaning due to shrinkage. The performance in terms of filtration efficiency and pressure drop is likely to get affected at higher temperature. Gas viscosity tends to increase at high temperature which can influence cake characteristics and differential pressure across the media. High temperature can also lead to more volume flow through the media. The impact of fabrics type is very small compared to the dust concentration and the temperature, but the effect of dust concentration is more severe than the temperature. [18]

Another arduous situation is the porosity in which, it is a very important structural property, since a drop in the filter's pressure during the filtration operation and the forces needed to removing the powdery layer depend on this parameter. In gas filtration, particularly demisting, the provision of a filter unit in the gas stream inherently results in a pressure drop, which increase operating costs. The pressure drop across the demisting unit should be therefore remain as low as possibility at an industrially acceptable minimum gas velocity together with the maximum capturing efficiency. Particularly, when the mist to be filtered out contains a considerable amount of submicron particles, the gas stream which is to be filtered should remain in the filter for at least a certain minimum length of time. Indeed, the submicron particles capture mechanism is based upon diffusion of these particles from the gas stream to the filter mass example composed of fibers. This diffusion is based upon the Brownian movement of the very small particles in the gas stream and required a certain contact time to allow migration of the particles to the filtered fibers. Thus, the applied gas flow rate generally cannot rise above a certain value without the need for a corresponding increase in the filter thickness which would result not only in high installation costs but also in higher operational costs since the pressure drop in the gas stream would be increased. The demisting filter currently used for submicron particles generally contain glass fibers mats as a

filter medium but these filters suffer from the disadvantages that they tend to produce a considerable increase in pressure drop with high capturing efficiency. This is probably due to low porosity of the filters, the pores which rapidly tends to obstruct, resulting in a rapid increase in a pressure drop. According to new invention filtration apparatus for removal of particles from a stream of gas, comprising filtration mean containing a filter material composed at least 0.985, means for passing a stream of gas containing particles through said filtration means and means for removing from said filtration means the said stream of gas from which at least a portion of the said particles have been removed. The porosity is calculated by taking in account the areas, thickness, weight, volume and then density of the fabrics is getting. This calculated density is taken in ratio with the actual density of the material and then the relative density is getting. The porosity (E) of the web corresponding to (1 – relative density). [19,20]

2.9 Principles Used For Measurement of Filtration Efficiency:

From all the above condition the filtration efficiency is test in two ways (only air filtration):

- Weight test in which the difference between the weight of a filter before and after being test subjected to a standardized flow air containing standard particles is determined.
- A discoloration test has been employed which uses a photometric comparison between two filters, one of which is clean and the other of which subjected to standard air flow of air containing standard particles size. By comparing the colors of filters in the filters in devices known as a Dill Dust Spot Tester, the relative efficiency rate of the filter can be determined. [20, 23, 24]

Research Gap:-

Literature review shows that in earlier days people were using woven fabric as a filtering media. But with introduction of nonwoven fabric, that trend is shifted to nonwoven fabric. This is because nonwoven fabric has very fine pore size compare to woven fabric structure, good permeability and comparable bursting strength with woven fabric. Today's filter uses single type of fiber with same fiber denier. As air contains variety of particles with different size and chemical nature, filter start chocking over a period of use and develops higher pressure difference and result is to change filter fabric.

So there is a need to develop filter which will entrap all types of particles affecting performance of a filter to which it is designed for and give longer working life. This will not only improve service life of filter but also reduce number of changes of filter fabric which will reduce cost of filtration.

3. Object of Research/ Proposed Hypothesis

1. To design and develop nonwoven fabrics for air filtration.
2. To evaluate performance characteristics of developed samples.
3. To explore suitable application of developed nonwovens.

4. Methodology

4.1 Raw Material

For this work natural fiber and synthetic fibres will be used which are easily available in the market. eg . polyester, polypropylene and its blends.

4.2 Fabric Manufacturing

Nonwoven needle-punched & thermal bonded fabric will be produced with different types of fibres and with different GSM.

4.3 Testing

Testing Parameters	Machines	ASTM Standards
Raw material		
Fibre length	Grease Plate Technique	D 3822 - 14
Tensile properties of fibre	Instron Tensile Tester	D 3822 – 01
Nonwoven fabrics		
Tensile properties	Instron Tensile Tester	D 5035 - 11
Tear strength	Tear strength tester	
Air Permeability	Air permeability Tester	D 737-96
Fibre Orientation	Lenzing Instrument NOS-200	
Pore size	Capillary Flow porometry	
Thickness	Digital Thickness Tester	D 5729-97(2004)
GSM	GSM cutter and Balance	D 6242-98(2004)
Filtration Efficiency	Filtration efficiency tester	

All results will be analyzed statistically.

4.5 Area of Application

The results developed using needle punched fabric will be explored to various air filtration applications in automotive, home, food products, chemical industry, coal fire power stations, face mask etc.

4.6 Statistical analyses using ANOVA

A test results are analysed by using suitable statistical tool before making any final conclusion. For statical analysis MINITAB software will used.

5. Importance of study

Nonwoven fabric being low in cost and comparatively superior filtration properties over woven fabric is the basic motive behind this study. A non woven Textile material exhibits good filtration property because three-dimension network of fibers enclosing small pocket of void and good at properties like air permeability, size of pores, bursting strength and porosity. This work will help in developing the nonwovens fabrics with respect to specific air filtration applications.

6 Proposed work Plan

Year-wise Plan of Work and Targets to Be Achieved

The proposed work plan along with the time line to complete the entire experimental work is as given below.

Sr. No.	Activity	Time Period (Months)
1	Procurement of Raw Material	1.0
2	Testing of Raw Material	1.0
3	Manufacturing of nonwoven fabric by needle punch & thermo bonding	2.0
4	Testing of fabric	1.0
5	Selection Nonwoven technology suitable for air filter fabric	1.0
6	Develop intake air filter for automobile and compare with exiting	10.0
7	Statistical analysis	1.0
8	Designing of filtration efficiency tester	6.0
9	Material selection for the tester	2.0
10	Fabrication of the tester	2.0
11	Checking the reliability of the tester	1.0
12	Statistical analyses	1.0
13	Result and discussion, Conclusion	1.0
14	Thesis write up	6.0

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